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Technicians under the microscope: The training and skills of university laboratory and engineering workshop technicians

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Abstract: *The UK government aims to increase both the number, and also the status, of workers with intermediate-level skills, with a view to creating a 'modern class of technicians' who can help to bolster economic growth and prosperity. This article considers the prospects for such a policy by focussing on one particular, but neglected, group of technicians, namely those who work in university laboratories and workshops. Data from English universities is used to shed light on the recruitment, training, skills, qualifications, and career prospects of technicians. Factors shaping employer decisions about recruitment and training are examined, in the context of broader human resource management arrangements and the development of a new technician registration scheme.*

Keywords: Apprenticeship, training, human capital, technicians

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Technicians under the microscope: The training and skills of university laboratory and engineering workshop technicians

Abstract: *The UK government aims to increase both the number, and also the status, of workers with intermediate-level skills, with a view to creating a 'modern class of technicians' who can help to bolster economic growth and prosperity. This article considers the prospects for such a policy by focussing on one particular, but neglected, group of technicians, namely those who work in university laboratories and workshops. Data from English universities is used to shed light on the recruitment, training, skills, qualifications, and career prospects of technicians. Factors shaping employer decisions about recruitment and training are examined, in the context of broader human resource management arrangements and the development of a new technician registration scheme.*

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1. INTRODUCTION

Recent statements of skills policy issued by the UK coalition government, and by the previous administration, have emphasised the importance of increasing the numbers and status of technicians in the UK economy. As currently defined by policy-makers, a technician is someone who is skilled in the use of particular techniques and procedures to solve practical problems, often in ways which require ingenuity and creativity. Technicians typically work with complex equipment, requiring specialised training, as well as practical experience, in order to do their job effectively. Technician roles demand skills and qualifications which range from levels 3 (e.g. advanced apprenticeship), through Higher National Certificate / Diploma (HNC/HND), up to Foundation degree, and so encompass what have traditionally been referred to as skilled trades/craft roles as well as associate professional/technician roles (DBIS 2010: 7).

The goal of UK government policy is to create a ‘modern class of technicians’ (DBIS 2010: 7, 18). To this end, targets have been set for increasing the number of apprentice technicians (House of Commons Library 2011: 4-6). In addition, a Technician Council has been established in an attempt to increase career opportunities open to technicians and to ensure that the contribution made by technicians to their employing organisation and more broadly to society is better recognised (DBIS 2010; The Technicians Council 2011).

As the Technician Council has noted, such policy goals will be achieved only if the nature of technician work and the demand for technician skills is better understood (Technician Council 2011). The current article aims to contribute to this understanding, by exploring skills, training, and career routes of one important, but largely unstudied, group of technicians, namely those who work in university laboratories and workshops. It is true that there were an earlier set of studies of technicians (Loveridge *et al.* 1972; Meiksins and Smith 1986; McGovern 1998), but these focussed on technicians more broadly and on issues wider than training and skills. In addition, there are some notable US ethnographic studies of technicians, but again these do not focus on training (Barley and Bechky 1994; Barley 1996). In the UK, government policy documents on science and innovation have tended to neglect the role of university technicians, despite suggestions that a shortage of technicians may be hampering the work of university science and engineering (Evidence Ltd 2004; House of Commons 2009).

This article seeks to improve the knowledge base in the literature and in policy analysis by focusing on two sets of issues concerning university laboratory and workshop technicians. First, the article is concerned with how science and engineering departments satisfy their need for suitably skilled technicians. Second, the article explores the qualifications and skills technicians actually possess and ideally require to perform their jobs. In doing so, it enquires into whether qualifications and skills should be at intermediate level or at graduate level and above. This in turn relates to broader debates about the desired balance between the apprentice-type route and the higher education route to skills and knowledge (Holmes and Mayhew 2012).

The structure of the remainder of the article is as follows. Section 2 outlines some key theoretical issues pertaining to employers' decisions about how to acquire skilled labour. This is used to frame the article. Section 3 sets out research methods. Section 4 considers the nature of the technician workforce in university laboratories and workshops. Section 5 deals with recruitment and training. In section 6, there is a discussion of factors shaping employer decisions, key aspects of the broader Human Resource Management (HRM) context, and the idea of technician registration. In the conclusions, summary points and policy implications are outlined.

2. PERSPECTIVES ON EMPOYERS' DECISIONS ABOUT SKILLS AND TRAINING

There are three main sets of factors which shape an employer's decision about the level of technician labour to employ and how to source that labour. These relate to technological, labour market, and institutional dimensions

First, the technological dimension relates to the scientific discipline concerned and the related types of technician support. Thus as we shall see, at one extreme, there are some technician jobs where the tasks involved require sufficient knowledge of the relevant science that they can only be performed by someone with a degree. By contrast, the technologies traditionally supporting certain disciplines, especially areas of engineering, had a large practice-based component of tacit or craft skills, implying that such roles are best filled by people who are vocationally rather than university-educated. In turn, this suited traditional apprentice-type training. However, it may be the case that, as the nature of the science becomes more specialised and complex, so in turn there are pressures for support technologies to become more knowledge-based. In turn, this may produce pressures to recruit staff direct from universities, after the completion of an undergraduate degree.

Technology may also operate in another way. Thus, if it is more generic, then it may push employers more towards recruitment of staff with more general craft skills or scientific knowledge, respectively apprentices or graduates. If it is rather more specific to the organisation, this may push organisations towards internal training of an up-grade kind. In the detailed cases below, we will see a number of significant changes in the technological support provided for university engineering and science.

Second, there is a labour market dimension, shaping employers' decisions about skills and training. Organisations must choose between various alternatives for sourcing their skilled labour. The first key decision concerns the balance to strike between recruitment – that is, hiring workers who already possess the relevant skills from the external labour market, including both technicians and graduates – and some form of training. Contemporary economics tends to view the employer's decision about the extent to which it should rely on training through the lens provided by the theory of human capital under imperfect competition. This approach portrays employers as inhabiting a labour market where – because workers' skills are only transferable, in the sense of being valuable to some but not to all firms, or because employers are uncertain about workers' skills, or because it is costly for workers to search for a new job - competition is insufficient to drive up wages until they are equal to workers' marginal product. Employers therefore enjoy a degree of market power and, as a result, are able to pay skilled workers a wage that is less than their marginal product without losing them to rival firms. This gives employers an incentive to bear some of the costs of training, because, although they have to pay newly trained workers more in order to retain them, the wage rise is smaller than the increase in the workers' marginal product, so that employers obtain a positive return. Moreover, in labour markets of this kind recruitment is costly, not only because employers have to pay higher wages to attract skilled workers from the external labour market but also because the higher wage must also be paid to current employees. Employers will minimise the costs of acquiring the skilled labour they need by relying on a combination of training and recruitment, with the role of training increasing as its marginal cost declines relative to that of recruitment (Stevens 1994: 537-41; Acemoglu and Pischke 1999; Wolter and Ryan 2010).

A noteworthy possibility when it comes to recruitment is that employers may fill technician roles, not by hiring people with technician-level skills and qualifications, but by recruiting graduates. Where employers behave in this way, then we have a case of what is known as over-qualification; the highest level of formal qualifications possessed by the workers in question exceeds the level required actually to carry out their job effectively (Wolf 2011: 29). Evidence indicates that the over-qualification is quite widespread in the UK economy, with somewhere in the region of one quarter and one third of UK employees falling into that category (Chevalier and Lindley 2009; Green and Zhou 2010; UKCES 2014: 46).

To the extent that employers rely on in-house training to obtain their skilled workers, there remains the question of what kind of training to use. A broad distinction may be drawn here between apprenticeship and up-grade training. An apprenticeship is a contract between an employer and a person that: combines a structured programme of on-the-job training and productive work with part-time, formal technical education; normally takes at least three years to complete, after compulsory general education; is usually formally certificated; and equips people with intermediate (level 3-5) skills, of the kind required by technicians (Ryan 2000; Fuller and Unwin 2006 and 2012; Steedman 2011).[1] Apprenticeship training is oriented to the requirements of what economists refer to as *occupational* labour markets (OLMs) (Marsden 1986: 234-36, 239; Marsden and Ryan 1990: 351-52). An OLM is associated with the standardisation across employers of the job description, level and mix of skills, and the form of training, associated with a particular occupation. In order to ensure that workers obtain the broad, all-round competence that makes such labour mobility possible, OLMs require standardised training programmes – incorporating off-the-job vocational education as well as on-the-job practical training - that lead to 'the development and certification of skills on a basis wider than the needs, resources and inclinations of individual employers' (Marsden and Ryan 1991: 253) so that trainees develop a 'wide-ranging … individual capacity or potential within a broadly defined occupational field' (Brockmann *et al*. 2010: 113).

[1] Defined thus, apprenticeship (with a lower-case 'a') may be distinguished from 'Apprenticeship' (upper-case), which term denotes in the UK a set of governed-funded work-based learning programmes, some – though not all – of which may differ from 'apprenticeships' in offering training only to level 2 and in having no worthwhile off-the-job component (Ryan *et al*. 2006, 2007: 129).

OLMs are typically contrasted with internal labour markets (ILMs), which may be defined as formal and informal institutional processes governing wages, skill development, promotion opportunities, and career employment paths within particular organizations (Doeringer and Piore 1971; Marsden and Ryan 1990: 350-54, 1991: 253). As this definition indicates, ILMs are organised around the needs of particular employers. Whereas apprenticeship training is oriented towards the standardised requirements of OLMs, training in ILMs is tends to be closely tailored to the requirements of individual employers and, more specifically, to the immediate requirements of a particular job in the relevant organisation. Up-grade training involves the training of employees, of all ages, employment tenures, and educational backgrounds, for more skilled jobs as they progress through a career. In contrast to apprenticeship, upgrade training tends to be provided on-the-job, with little or no off-the-job vocational education; is more closely tailored to the requirements of the particular job role for which the person is being trained; is often uncertificated; and prepares workers – who may be recent recruits or more established employees and who may have a broad range of ages and prior skill and qualifications levels – for (in this case) technician-level roles. Compared to a good apprenticeship, therefore, upgrade training may be limited in breath, generality, duration, and (therefore) cost. Moreover, the fact that upgrade training is often uncertificated, and given to established employees whose loyalty is likely to be greater than that of recently-recruited apprentices, implies that its recipients are less likely than apprentices to leave for another employer. By relying on upgrade or task-based training rather than apprenticeship, therefore, employers seek to reduce both their outlay on training and also the risk of not making a return on that investment because of the loss of skilled employees to other organisations. However, employers will prefer apprenticeship where the external supply of skilled labour is limited and where skill requirements and the need for underpinning knowledge are high (Ryan 1995: 30-32; Ryan *et al*. 2007: 128, 130, 137; Brockmann *et al*. 2010: 113-14).

In practice, of course, recruitment, apprenticeship, and up-grade may not be alternatives and may well be combined. Just what combinations occur in the case of specific employers is the empirical question at the core of this paper.

Third, in discussing employer decisions, there is an institutional dimension which must be considered. Here we refer to two sets of institutions, one within and the other outside the organisation. Within the organisation, HRM practices will shape the decision as to whether to recruit or train. The so-called 'fit' between such practices and training may be loose in the sense that job tenure, promotions, and pay may not be related to training. In these circumstances, if employers train, they may lose staff, and this in turn may eventually lead to a reduction in training and an increase in recruitment. If the fit between training and other HR practices is tighter, so the benefits of training can be expected to accrue more to the employer who provides it than to competitors, and the use of training relative to recruitment is likely to increase. In the terminology of HRM, in order to be effective training needs to be 'bundled' with a variety of complementary practices (Guest *et al.* 2003; Boxall and Macky 2009). Where this integration occurs, the preference may be more for upgrade training over apprenticeship since, as stated, the former may also be cheaper and less risky. If the employer does resort to apprenticeship-type training, then once again this will have to be integrated into HRM if it is to be effective.

Outside the organisation, there are various institutions which may shape skills and training. These include *inter alia* the state, the education system, trade unions and professional associations. Here we refer to one significant one which has recently been suggested for technicians, viz. occupational regulation via workforce registration. As we will see in section 6, there is at present considerable discussion of the registration of the technician labour force (where by 'registration' we mean a process whereby an agency, voluntary or statutory, records the names and relevant details of individuals who work in a particular occupation). This we deal with in more detail below. However, here we state that there is some evidence that occupational regulation, in the form of licensing, certification, and registration, can positively affect employer decisions about the types of labour to employ and whether to train and can provide an institutional check on market failure (Kleiner 2006 and 2013; Lloyd 2005; Forth *et al.* 2011; Tamkin et al. 2013).

The paper therefore addresses the following research questions. First, to what extent do universities still use technicians? Second, how do UK university science and engineering departments satisfy their need for suitably skilled technicians and is this via recruitment or training? Third, to the extent that universities rely on recruitment to fill technician roles, do they recruit people with technician-level skills and qualifications or do they recruit (over-qualified) graduates? Fourth, in so far as the demand for technicians is met by training, what is the shifting balance between apprenticeship and upgrade training? Fifth, how are employer's decisions shaped by the following factors: changing technological demands, labour market constraints, and institutional factors?

3. RESEARCH METHODS AND DATA SOURCES

We rely on multiple data sources on university employers and their technicians. First, secondary sources, including government and sector reports, and data from the Higher Education Statistics Agency, are used. In addition, we also carried out 31 interviews with government departments, funding bodies, sector skills councils, learned societies, and technicians' organisations. Wherever possible, documentation was collected in the form of both published and unpublished materials.

Second, we used a case study approach which allowed us to explore employers and technicians in more detail - though the intention was not to provide an ethnographic study as in the US work cited above. Rather the goal was to select a spread of cases which were similar in many ways but which differed in particular attributes of interest discussed above (e.g. same type of university, similar labour markets, but different disciplines), and to use comparisons between them to highlight key influences on skills and training strategies. For example, cases were selected: to include both engineering and biological sciences (on the basis that the former might be more likely to recruit workers from local industry, while the latter might rely on national markets for graduates); to include both pre-1992 (research-intensive) and post-1992 (more teaching-intensive) universities (because of the potentially different roles and skills required of technicians in those universities); and also to include different locations (and, therefore, potentially different local labour market conditions). In total, case studies were conducted in 45 departments covering four science disciplines, namely engineering, physics, chemistry, and biological sciences (including biochemistry, pharmacology, plant science, and zoology and hereinafter referred to as biosciences). The cases were drawn from 18 different English universities, 14 pre-1992 and 4 post-1992, covering London and the South East, the Midlands, the North-West, and the North of England.

Information was collected via semi-structured interviews with academics, technical services managers, and technicians, using a schedule piloted in the early cases.[2] A summary of the cases is provided in Tables 1 and 2.

-- Insert Tables 1 and 2 around here --

A total of 96 interviews were conducted in the case study organisations. A majority were face-to-face, but with 7 taking place by telephone. Interviews averaged 90 minutes in length. Where gaps were revealed, these were filled by telephone or email follow-ups. Primary and secondary documentation was also collected from the departments where available. The period of the research was over one year from summer 2010 to summer 2011.

4. RESULTS I: THE CURRENT TECHNICIAN WORKFORCE: NUMBERS AND ATTRIBUTES

4.1 Numbers,

Figure 1 presents UK data for technicians in our four disciplines over the period 2003/04 to 2009/10. Overall, the largest number of technicians are to be found in the biosciences and engineering, with chemistry and physics quite some way behind. Over that period, the absolute number of technicians has declined by 14% in engineering, by 11% in chemistry, and by 8% in physics, with the biosciences relatively stable (displaying a decline of just 1%).

-- Insert Figure 1 around here --

[2] The interview schedule is available upon request from the authors.

In our case studies, there was also said to be a reduction in numbers, over the past decade, both absolute and also relative to the number of academics and students supported. Most interviewees stated that this had not yet led to significant difficulties in providing support for research and teaching. However, academics and managers in four bioscience departments said that teaching support had deteriorated and five of the departments in post-1992 universities were concerned that they did not have the support to meet increasingly demanding research targets.

4.2. Technician roles and qualifications

A number of different technician roles can be found in university science and engineering departments. Here we outline the main kinds of role, focusing on those of most significance for answering the research questions posed above.

First, 'mechanical and electronic workshop' technicians are involved in the design, construction, maintenance, and use of equipment for research and teaching. The largest numbers of such workers are employed in engineering and physics laboratories but they are also found in chemistry and bioscience departments. The vast majority (90%+) of mechanical and workshop technicians have vocational qualifications in mechanical and electronic engineering, usually City&Guilds or HNCs/HNDs. The reason for the predominance of vocationally-trained workers in these roles is that the work-based route has traditionally been deemed to be superior for equipping people with the practical engineering skills – such as the ability to mill, turn, drill, solder, and wire – required to fill these roles than university degrees, where the time spent on practical training is low.

A second group, referred to as 'research laboratory' technicians, provides support for specific research groups, by preparing equipment and materials, conducting experiments, and analysing data. Such technicians are most numerous in chemistry and the biological sciences, though they are also to be found in lesser numbers in engineering and physics departments. Most research technicians in engineering and physics are vocationally qualified, the reason being – as noted above - their superior practical skills which renders them more suitable for the roles than graduates. Exceptions can be found in some physics departments, where the nature of the work undertaken by electronics technicians makes a degree highly desirable, and also in some engineering departments which conduct interdisciplinary work in bioengineering or chemical engineering, where technicians who have at least a BSc in the relevant science are employed to help run the laboratories and to provide scientific input into the design of experiments and the analysis of data.

In the biosciences and chemistry, however, while older research technicians have vocational qualifications, their younger counterparts tend to have BScs. This tendency was attributed principally to technological change - such as the ability to automate experiments, such as DNA sequencing which previously had to be conducted manually – which has rendered the practical skills possessed by those older technicians less relevant. The premium is increasingly on technicians who – rather than carrying out tasks manually - can help with the design of experiments and analyse the data produced. Since those skills are most likely to be acquired via a degree, rather than through vocational training, it is perhaps unsurprising that research technicians in bioscience and chemistry are increasingly graduates. Graduates were also said to have a better grasp of scientific principles underlying much research and to be able to operate with less supervision. A majority of the pre-1992 bioscience departments concluded that a first degree has become a prerequisite for a research technician post. That is to say, it is increasingly the case that research technician roles in the biological and chemical sciences are in fact not 'technician' roles at all, at least as that term is usually defined, because they no longer require the intermediate-level skills that are one of the defining characteristics of a technician job.

Third, in every department, across all four disciplines, 'teaching' technicians support teaching by preparing equipment and materials and overseeing their use in classes. In pre-1992 universities, the qualifications of teaching technicians depended on their degree of involvement in teaching: those who merely supported teaching had at most a vocational qualification; those who were more actively involved tended to be qualified at least to vocational level and some, in biosciences and chemistry, possessed undergraduate and even higher degrees. In the post-1992 universities, where the teaching role is more predominant, most of the technicians in engineering and physics departments had vocational qualifications, with the exception of one engineering department where most of the technicians had an undergraduate degree. In the pre-1992 universities, at least two thirds of the teaching technicians in biosciences had a degree, with many having an MSc or even PhD.

4.3 *The 'fit' between technician skills and qualification and universities' requirements*

There is the important question as to whether academics and technical managers believed that there was a good match in skills between what was actually current and what was ideally desired for their departments' needs. Such a gap in the skills profile could take the form of either under-qualification or over-qualification. In practice, many interviewees felt there was a satisfactory match.

First, so far as the problem of under-qualification is concerned, around half the engineering departments, and some of the physics departments, said they wanted more technicians with mechatronic skills (i.e., with the ability to integrate mechanical and electronic systems). Other engineering departments said they would like to have more technicians with higher 3-D CAM-CAD knowledge. In biosciences some interviewees indicated that the rapid pace of technological change, in particular the automation of experimental procedures and the introduction of new data-handling techniques, had left some older research technicians with skills peripheral to departmental needs. Early retirement and voluntary severance schemes in universities have only partially helped to alleviate this problem.

Second, in terms of over-qualification, interviewees from bioscience departments, both in pre- and post-1992 universities, said that they employed (often large numbers of) teaching technicians with degrees and even with MScs or PhDs to fill teaching technician roles for which nothing more than intermediate-level qualifications are adequate. The graduates who fill those roles are over-qualified in the sense that the highest level of formal qualifications they possess exceeds that required actually to carry out their job effectively. In effect, departments under-utilise their skills. As we shall discuss in section 5.1, this reliance on graduates reflects the fact that bioscience departments find it very easy to fill technician roles via external recruitment.

4.4 Job tenure and the age of technicians

The majority of technicians were on open-ended, rather than fixed-term, contracts. This varied from a low of around 80 per cent in bioscience to a high of 90 per cent in physics. Labour turnover was universally reported to be very low, with many departments reporting turnover of less than 5 per cent and almost all with less than 10 per cent. In theory, this stability should encourage training. On the other hand, representatives of bioscience and engineering departments in particular, pointed out that skills may cease to be relevant. This is particularly the case where staff are unable or unwilling to be retrained or where departments fail to provide up-date training.

The average age of technicians in engineering, physics, and chemistry is around 50 years. Roughly half the technicians in these departments are due to retire within the next 15 years. Matters are rather different in biosciences, where the average age is around 40 and where around 40-45 per cent are likely to retire within the 15 years. As we will see, this reflects a tendency in recent years for bioscience departments to recruit relatively young graduates to technician posts. Age profiles of the kind found in engineering, physics, and chemistry are the cause of much concern, voiced both by interviewees and also by commentators (Evidence Ltd 2004: 14-15).

A succession planning problem therefore exists which academics and managers said must be addressed if technical support is to be assured. Of course, quite how serious the problem is depends on how easily suitable replacements for retirees can be found. This leads to the key set of issues at the core of this article: the kind of qualifications and skills technicians currently have; the kinds which departments require;

and how skills are to be obtained in the future, whether by recruitment or training and what kind of training (apprenticeship, up-grade, or university).

5. RESULTS 2: WORKFORCE PLANNING

5.1 Current workforce planning strategies: Recruitment versus training?

We turn to the routes which departments are taking to address workforce planning and resourcing issues, such as the impact of technical change and the need for orderly succession of an ageing workforce. We consider first recruitment and then training, both initial apprentice-type training and on-going training for existing staff.

5.2.a. Recruitment

Interviewees indicated that external recruitment has been the main method whereby technicians of all kinds have been obtained during the past 15-20 years. However, it was also suggested that over the past 5 years there has emerged a contrast between bioscience and chemistry departments, which easily recruit a large number of graduates as technicians, and engineering and physics departments, which are increasingly struggling to recruit the kind of workers they require.

Interviewees from all 13 of the bioscience and 9 out of 11 of the chemistry departments said they receive large numbers of applicants for technician posts of all kinds except for mechanical and electronic workshop technicians, with ratios of 50 or even over 100 applicants per place being mentioned for research and teaching technician posts. In turn this reflects two factors: the abundance of relevant graduates produced by UK universities and the reduction in employment in chemical and pharmaceutical companies. Several interviewees remarked that even advertisements for low level teaching technician posts attract significant interest, often with over one hundred applicants for each position, not only from large numbers of graduates but also from those with advanced degrees. Even when unsuitable candidates are excluded, bioscience and chemistry departments are usually left with many strong candidates from which to choose.

The abundance of appropriate labour means that bioscience and chemistry departments, when considering succession planning and workforce renewal, are able to rely on recruitment from the external labour market. Consequently, no bioscience or chemistry department among our cases currently runs an apprenticeship programme for its research or teaching technicians. The contrast with engineering and physics departments is stark. A majority of these, in all parts of the country, said they found it difficult to recruit technicians, in particular those who work in mechanical and electronics workshops, from the external labour market. In the words of one interviewee: 'It's not easy, and it's getting worse…. You have to be lucky to get a good one'. Two reasons were given for this. First, the salaries paid by universities, which are said to be low relative to that in industry, make it hard to attract younger technicians in particular. Second, the long-term decline of engineering and related companies which traditionally trained technician-type staff and the scaling back of training programmes in surviving companies has led to a reduction of the pool from which experienced technicians can be drawn. According to one technical services manager, 'The well's run dry'.[3]

[3] Far from being confined to universities, difficulties in hiring experienced engineering technicians are widespread in advanced manufacturing, being found for example both in the aerospace and space industries (Lewis 2012a: 21-22, 2012b: 25-26).

5.2.b Apprenticeship training

For this reason, coupled with an ageing workforce, there has recently been a revival of apprenticeship training by engineering and physics departments. At the time of our research, six of the 12 engineering and three of the nine physics departments had either recently begun, or were about to begin, apprenticeship schemes for technicians. Two other engineering departments, and one other physics department, were formally considering such a scheme.

We have already mentioned two reasons for this renewed interest in apprenticeship training in engineering and physics – an ageing workforce and the difficulty of obtaining suitably qualified skills on the external labour market. A further reason for these developments is that apprenticeship is seen as a way for departments to update workforce skills, especially when apprentices take a mix of units in mechanical and electronic engineering, thereby acquiring the mechatronic skills which many departments now require. Moreover, upgrade training will not suffice in this regard because workshop technicians are said to need the broad range of skills, and underpinning knowledge, provided by the broad experience and off-the-job training associated with a traditional apprenticeship. Nor will recruiting people who have just completed an undergraduate degree, the reason being that undergraduate degree courses place little emphasis on the practical, craft skills of milling, turning, drilling, etc., that engineering and physics workshop technicians need to possess.

In all 9 cases, apprentices are recruited under the auspices of the government's Advanced Apprenticeship programme. Apprentices typically work towards an NVQ3 and an ONC in engineering, often with a view of ultimately progressing to an HNC. All 9 departments have delegated formal responsibility for the running of the scheme to an external training provider - 7 to local colleges, one to a private training provider, and one to a group training association – which holds the contract with the Skills Funding Agency.

However, the number of apprentices in question is small, averaging just one or two per annum in each university. The ratio of apprentices to technicians is around 3 per cent in physics and around 5 per cent in engineering departments. The figures are expected to rise, if departments, most of which have only recently begun to take apprentices again, continue to do so and therefore come to have apprentices in all three or four years of their programmes.

Five of the 12 departments of engineering and physics which had not taken on apprentices at the time of our research had seriously considered doing so. However, despite acknowledging the potential of apprenticeship, they decided against for two reasons. First, two departments feared they would have to pay excessively high wages to retain newly qualified apprentices. These departments said they might well revisit their decision in the future. Second, some departments were concerned that current technicians were already stretched and would not have the time to provide on-the-job training. As one technical services manager put it: ‘We don’t have the time… and would have to take on an extra trainer to do it’.

Those engineering and physics departments which have not seriously considered taking on apprentices either still have a relatively young workforce or claim they can still find pools of labour in the external market. In other words, two of the main factors considered above (an ageing labour force and difficulty of recruiting externally) are not present. The absence of one or both of these factors also accounts to a large extent for the fact that none of the 24 bioscience and chemistry departments is currently running an apprenticeship programme for its technicians.

5.2.c. On-going training

We turn to on-going training for existing staff. Though increasing use is being made of formal appraisal reviews, nevertheless, interviewees in a significant minority of departments indicated that this remains *ad hoc*, driven by short-term requirements of current research projects, rather than systematic appraisal of the longer-term needs of the individual and the department. Moreover, in a handful of departments, especially in engineering, appraisals have only recently been introduced. In others, while systems are formally in place, they are not popular, especially among older technicians, and in practice appraisals may sometimes not be carried out.

On-going training may be either certificated or un-certificated. Certificated training, leading to formal qualifications, is the least common. Nevertheless, around a fifth of departments have sent non-apprentice technicians on certificated vocational courses, such as BTECs, HNCs, and HNDs. In addition, there were cases where departments would like to send staff on such courses, but this is constrained by the absence of courses in near-by colleges. This was true in the case of engineering and physics departments which have struggled to find colleges offering HNCs in electronics. It also applies to some bioscience and chemistry departments which, in the light of the difficulties caused by over-skilling, would like to have some of their teaching technicians take HNCs or BTECs in applied biology and chemistry.

In the case of academic certification, a majority of the chemistry, engineering, and physics departments have also sponsored small number of technicians – typically just one or two - on BScs and three more have supported technicians on an MSc. Those technicians, especially technical officers, who have a PhD, have often acquired this via research and publications undertaken whilst working as a technician.

Most uncertificated training involves up-skilling on-the-job, with the assistance of other technicians or academics who are able and willing to give of their time. Another important source of uncertificated training is that supplied by equipment manufacturers. Training of this kind usually accompanies the purchase of new equipment and/or associated software, though it can also be obtained independently of the latter.

However, significant obstacles to ongoing training were mentioned. We have already referred to the perceived problems in terms of the supply of suitable courses offered by colleges. Here we cite three others. First, it is often hard to release technicians, given demands on staff. In this respect, while some academic staff are very supportive of release for training, others were said to be less helpful. The upshot is that while research technicians may become expert in the specific set of techniques required to support the work of the group or laboratory to which they are attached at one particular moment in time, they may lack opportunities to acquire a more rounded technical education which suits them for a broader array of posts. Second, there are significant and growing financial constraints. Not surprisingly, technical services managers prefer to cut training budgets rather than cut staff. Third, a minority of technicians, especially older ones, were said to be often unenthusiastic about training. According to one manager, technicians have sometimes 'devalued themselves' by neglecting to update their skills, as a ‘professional’ approach would require. This is particularly the case where, as in biosciences and to a lesser extent engineering, skill requirements have changed fast and old skills have become increasingly peripheral. Early retirement and voluntary severance have alleviated some of these problems, but not eliminated them altogether.

All in all, on-going training is important for creating an optimal skills mix for departments. However, as organised in universities, it does not provide a systematic form of up-grade training which might constitute an alternative to the external recruitment of sufficient staff or the internal training of apprentices.

6. DISCUSSION

In this section we return to the issues outlined in the introduction and focus on three sets of questions which have informed the analysis. First, how do we explain the patterns of workforce resourcing and planning in the four disciplines across different universities and labour markets? Second, what is the balance in training between apprenticeship training, the use of graduates, and upgrade training on the job? Third, how do skills and training strategies relate to broader HRM considerations and practices? Relatedly, is there a role for another kind of institution, namely the registration of the technician labour force? In turn, these questions relate back to the technological, market, and institutional dimensions of technician skills and training which were outlined in the introduction.

6.1 The influence of technological change

Technology, in the sense of the types of technical support for particular disciplines and sub-disciplines, shapes some decisions about the kind of labour to employ and how to source that labour. Thus, there is some technician work – such as cross-disciplinary work in bioengineering and chemical engineering, and electronics work in physics - which we were told now requires a degree. Also, as noted above, rapid technological change in recent years is a factor making it desirable for research technicians in the biosciences to have the kind of analytical and data handling skills best acquired through a degree. In this respect, research technician roles in the biological and chemical sciences mirror a general trend within the economy as a whole, whereby technical change is driving up the skills levels required by employers and leading to a decline in the overall need for technicians (although there remains a net positive demand for technicians overall due to the need to replace retiring members of an ageing technician workforce, a point to which we shall return below in the context of university technicians) (Spilsbury and Garrett 2011).

However, in other areas, such as the increasing demand for mechatronic skills in engineering and parts of chemistry, skills still seem best acquired via broad apprenticeship training. The reason is simple: much of the work required of engineering workshop technicians involves them building experimental rigs, instruments and other pieces of apparatus, the skills required for which are best acquired through an apprenticeship. Technical change is not yet undermining the need for technicians of this kind in universities.

While our evidence unfortunately does not permit us to assess in greater detail the relationship between the science, its supporting technology, and skills and training, it is clear that the changing demands of the technology used in research and teaching shapes, without uniquely determining, many skill and training decisions.

6.2 Labour market factors

Labour market and human capital considerations also clearly influence skills and training decisions. Thus, we have seen a strong contrast between the biosciences and chemistry on the one hand and engineering and physics on the other. In the former, there is an abundant supply of skilled labour in the form of graduates, and departments have increasingly recruited such labour into technician jobs, even in cases – such as teaching-related roles in the biological and chemical sciences in particular, – where the duties associated with the role can be quite satisfactorily discharged by people with skills and qualifications below the graduate level. However, the over-skilling to which this reliance on graduates gives rise can create problems. In particular, the graduates in question often become dissatisfied with their lot, partly because they are not stretched intellectually by the menial nature of their job, partly because of unhappiness with the fact that they have little autonomy, and also because of their relatively low wages. This is especially problematic where, as is often the case in universities, promotion prospects from entry-level positions to more senior roles is limited (see section 6.3 below). Such findings are consistent with evidence drawn from national skills surveys which indicate that where over-qualification is associated with a genuine under-utilisation of the skills of graduates, substantial job dissatisfaction results on the part of the employees (Green and Zhou 2010). [4]

On the other hand, in the case of engineering workshop technicians in physics and engineering departments, there is a scarcity of relevant labour and departments have had to look to apprenticeship training, which is expensive and risky, but which promises to

[4] A similar reliance on over-skilled graduates has been identified in the case of the laboratory technicians who work in other sectors such as the UK chemical industry (Lewis 2013).

generate a supply of the requisite labour. Moreover, this depends on a number of factors: how apprenticeship is structured; whether departments can hold onto their apprentice-trained labour; and whether external institutions support apprenticeship-type training. In this context, the practices and institutions of HRM and occupational regulation are important.

6.3 Internal institutions: HRM issues around careers and status

Above we mentioned various aspects of HRM in these departments within their universities, some of which are supportive of training and some of which less so. Overall, one positive factor is that jobs are relatively secure and staff are on open-ended contracts (see Section 4.4 above). The downside of this was also mentioned in terms of skills being superseded. In addition, we described how the incidence of more formal appraisal has increased, while noting also that in a significant minority of departments it remains *ad hoc* and in others is sometimes not carried out at all. In the background, we also suggested that finance is a major constraint on HRM and training of all kinds and is felt to have constrained the pay levels of university technicians compared to those in the private sector. There are two other HRM-type issues which are relevant, concerning careers and status.

First, on careers, many of our technicians had reached the top of their current grade. As a result, the scope for increased pay is limited to a small number of discretionary points, but these are also increasingly difficult to attain, especially given the current financial situation. Re-grading is also possible, but this in turn is difficult to obtain unless the nature or range of tasks change significantly. Another way for these pressures to be eased is via promotion. However, the relatively flat organisational hierarchies, and correspondingly limited ILMs, which characterise university science and engineering departments mean that they have few senior technical positions. Moreover, long tenures imply that once occupied senior technical positions tend to remain filled by the same person for many years. Taken together, these considerations ensure that the scope for promotion is usually limited. Interviewees repeatedly used the same phrase, namely ‘dead men’s shoes’, to describe this situation.

A further way to ease pressures might be for technicians to be able to make career moves on an inter-departmental or inter-university basis. Inter-departmental moves do happen, but are not common, being constrained by the range of skills acquired and mind-sets which one interviewee dubbed ‘parochial’. This relates to the point already mentioned, viz. that departments need to be more willing to offer, and technicians more willing to accept, opportunities for training in broader skills. Inter-university moves, and indeed moves out of the sector, do obviously take place. However, such moves are not likely to encourage training by individual departments.

Second, and related to careers, is the question of status. While the academics who work with them were said usually to appreciate the technicians’ contributions to teaching and research, it remains the case that technicians often feel underappreciated. In particular, interviewees reported that senior academics and administrators from outside the sciences often betray a misunderstanding of the technician role by making comments to the effect that technicians do little more than organise equipment which is used by academics, making no significant contribution to research, and that therefore they need little training. As one technician put it, ‘People don’t know what we do.’ This is sometimes said to lead in turn to a neglect of technical support by universities when strategic and HR plans are devised. To quote the phrases used by a number of technical services managers, technicians are ‘a forgotten workforce’ who are all-too-often ‘taken for granted’ and treated ‘as a bit of an afterthought’

At root, this reflects the fact that technicians’ work stands at the interface between manual and mental labour. The danger is that, if the more knowledge-related aspects are not acknowledged, then technicians’ work is associated only with physical effort and is therefore accorded low status. Moreover, because their role is to support and facilitate the work of another, more ‘eminent’ occupation, which is also widely seen to exercise authority over them, technicians’ contribution to research tends to remain invisible, with the result that technicians’ standing is not commensurate with the true significance of their work (Shapin 1989; Barkley and Bechky 1994: 91, 116).

Thus, although university HRM evidences some areas of fit between HR and training, nevertheless HR practices do not powerfully promote training, of either an apprenticeship or up-grade type, over recruitment. This therefore leads us to another possible means to encourage employers and technicians to avail themselves of training, namely registration.

6.4. External institutions: The prospect of registration

We define registration as a process whereby an agency, voluntary or statutory, records the names and relevant details of individuals who work in a particular occupation. A certain level of skill or possession of certain qualifications is usually a prerequisite for joining the register, and, to remain on the register, there may be requirements for continuing personal development (CPD) and on-going training. Those joining the register pay a fee and may have the right to a title or post-nominal of some kind (Sandford Smith *et al.* 2011).

The Technician Council, established in 2010, has as one of its aims to consider the establishment of voluntary registration for technicians in engineering, science, ICT, and health care. Under its auspices, relevant professional bodies, such as the Science Council and the Engineering Council, have undertaken to promote, where they already exist, or to establish, where they do not, standards to judge eligibility for registration, including requirements for CPD. Those with the requisite skills, qualifications, and experience and who pay a fee, will be able to use a title after their name (e.g., 'Engineering Technician' or 'Registered Science Technician' for those with level 3 qualifications in engineering or science respectively).

The objective of such registration schemes is to provide an incentive for technicians to seek initial and further qualifications and training and thereby enhance their grading and promotion prospects with employers. It is also envisaged that it will better signal the skills of technicians, thereby increasing their appeal to a broader range of employers and enhancing their wages and career prospects. It is noteworthy in this regard that the standards of competence that must be satisfied if someone is to qualify for a post-nominal such as Registered Science Technician or EngTech require the person in question to be able to discharge the duties associated with the job of, say, a laboratory technician or engineering workshop technician in a range of situations and across different companies within a sector, not just in a particular firm. In other words, the standards of competence are oriented towards the requirements of the relevant OLM rather than the specific needs of a particular employer's ILM (Richard 2012: 4, 32). Registering and achieving the relevant title is therefore a way for technicians to signal their skills and knowledge to other potential employers, helping those who have 'hit a ceiling' within their current department to seek promotion elsewhere. Ultimately, the aim of registration schemes is to improve the status and esteem in which technicians are held, thereby persuading greater numbers of young people to pursue a career as a technician. Recent UK research on occupational registration, certification, and licensing provides some evidence that some of these beneficial consequences may follow (Forth *et al*. 2011; Tamkin *et al*. 2013)

In our case studies, academics, technical services managers, and technicians themselves displayed cautious optimism about registration. Points made by interviewees were as follows. First, if registration were organised in the right way, this could encourage a more rounded technical education and training for technicians. For instance, by highlighting the breadth of competence needed for each level of professional status, the requirements for registration might help to provide research technicians with leverage to secure extra training beyond that required to support the current work of their research group. This should help to overcome the problem (noted in section 5.2c above) created by the narrowness of much of the CPD provided for university technicians. Second, any such scheme might have particular appeal to younger technicians who, as one interviewee put it, 'still have a career to forge'. Third, attaining registered status might be something which could figure in appraisal interviews, making them more real and more likely to result in positive training outcomes. Fourth, registration and the accompanying title might raise the status and esteem of technicians. Finally, registration could broaden the notion of a ‘career’, so as to encompass not just the current employer, but employers in other universities and outside the university sector.

7. CONCLUSION

This article has used new empirical research to investigate an important, but neglected, group of workers who make a significant contribution to research and teaching in the UK. The skills and qualifications of the technician workforce vary by discipline, role, and type of university and, overall, up to the present have been considered a decent match for departments’ needs. However, the age profile of technicians in engineering, physics, and chemistry is giving rise to succession problems. In addition, there are signs that developments, in the kind of research which is being done and in the technology which is being used, are leading to changes in the skills which departments would like their technicians to possess, as exemplified by the increasing demand for analytical and data-handling skills (especially in bioscience and chemistry) and for mechatronic skills (especially in engineering and physics).

We found a strong contrast between bioscience and chemistry departments on the one hand and engineering and physics departments on the other. The former use the external labour market and have increasingly recruited graduates; the latter face a shortage of technicians and are pursuing more mixed strategies, including a renewed interest in apprenticeship training. These differences we explained by a combination of technological and market factors. HRM practices play a mixed role in encouraging training. In this context, there has developed the idea of technician registration which potentially offers benefits, but faces real design challenges.

There are a number of policy implications. For employers, university managers, and academics, there must be doubts about the sustainability of the various skills strategies: the aftermath of the financial crisis militates against apprenticeships and against continuing training; the reliance on graduates may also prove unsustainable if the increase in student fees reduces the supply of graduates in these areas; meanwhile on-going and up-grade training is provided in a piecemeal fashion related more to short-term rather than long-term considerations. Employers need to think longer term about labour supply. More specifically, they need to organise to find time for training for established technicians and for apprentices where the latter are used or being considered. There may also be scope to explore some kinds of joint action and group training associations. One potentially interesting approach that should be considered by chemistry and biological science departments in particular involves the use of Higher Apprenticeships. The latter involve the recruitment of young people post A-level, who are then provided with a combination of work-based training to develop their practical skills (as certificated by an NVQ) and technical education via day release at a local college or university (leading to a Foundation Degree in chemistry or biological science). Such an approach is being adopted by some research and development laboratories in the chemical and pharmaceutical industries, where employers find that it yields employees with a good combination of practical skills and theoretical knowledge (Lewis 2013).

For technicians themselves, it is more difficult to draw out policy implications, since for the most part they act very much as individuals. However, where possible, through their professional bodies, trade unions, and consultation arrangements within universities, they need to press for a more strategic approach to technician training. If a well-designed registration scheme is put into place, then individual technicians will have seriously to consider registration.

Finally, for government and other public bodies, there is a case for the dissemination of better information about apprenticeship and its encouragement where appropriate. Pursuant of a general policy interest in occupational registration (Forth *et al.* 2011; Tamkin *et al*. 2013), government might wish to consider greater support for the developing registration scheme in the sector. In addition, and as noted by Richard (2012: 107-08) and Lewis (2012a: 38-39, 2012b: 34-35), government also needs to consider adjusting the funding regime facing further education colleges so that they are confronted with sharper incentives to offer training for apprenticeship subjects of the kind that employers such as universities want their workers to have.

Table 1: Number of different kinds of case study departments and interviews

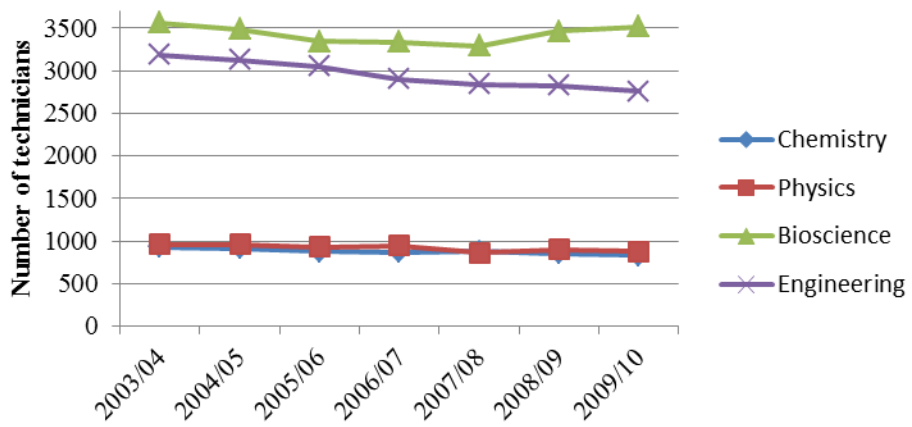
	Number of pre-1992 cases	Number of post-1992 cases	Total number of interviews	Number of academics interviewed	Number of technicians / technical services managers interviewed[a]
Biological sciences	9	4	28	11	18
Chemistry	10	1	17	8	14
Engineering	8	4	26	14	20
Physics	8	1	13	7	13

Notes:
a: 10 interviews were also conducted with HRM staff from 5 universities

Table 2: Summary of the case study departments

Mean number of: / Discipline	Academics	Postdocs	Undergraduates	PhD	Technicians	Technical Officers	Average ratio of academics to technicians
Biological sciences (13 departments)	52	67	552	92	37	3	1.3 (pre-1992) 1.9 (post 1992)
Chemistry (11 departments)	42	60	470	145	20	5	1.8 (pre-1992) 1.4 (post-1992)
Engineering (12 departments)	133	121	1340	367	53	4	2.7 (pre-1992) 2.0 (post-1992)
Physics (9 departments)	57	87	364	150	32	2	2.8 (pre-1992) 14 (post-1992)

Figure 3.1: Total number of technicians in bioscience, chemistry, engineering, and physics in UK Higher education, 2003/04-2009/10[a]



Source: HESA Staff Record 2003/04-2009/10.

REFERENCES

Acemoglu, D. and J-S. Pischke 1999. 'Beyond Becker: Training in Imperfect Labour Markets', *Economic Journal*, 109, 112-42

Barley, S.R. 1996. 'Technicians in the Workplace: Ethnographic Studies Evidence for Bringing Work into Organization Studies.' *Administrative Science Quarterly*, 41: 404-41.

Barley, S.R. and B.A. Bechky (1994). 'In the Backrooms of Science: The Work of Technicians in Science Labs.' *Work and Occupations*, 21: 85-126.

Boxall, P. and K. Macky 2009. 'Research and Theory on High-performance Work Systems: Progressing the High-involvement Stream.' *Human Resource Management Journal*, 19: 3-23.

Brockmann, M., L. Clarke and C. Winch. 2010. 'The Apprenticeship Framework in England: A New Beginning or a Continuing Sham?' *Journal of Education and Work*, 23: 111-27.

Chevalier, A. and J. Lindley. 2009. 'Over-education and the Skills of UK Graduates.' *Journal of the Royal Statistical Society* 172 (2).

DBIS. 2010. *Skills for Sustainable Growth: Strategy Document*. London: Department of Business, Innovation and Skills.

Doeringer, P. and M. Piore 1971. *Internal Labour Markets and Manpower Analysis*. Lexington, MA: DC Heath.

Evidence Ltd (2004). *Highly Skilled Technicians in Higher Education: A Report to HEFCE by Evidence Ltd*. Leeds: Evidence Ltd.

Forth, J., A. Bryson, A. Humphris, M. Koumenta, and M. Kleiner. 2011. *A Review of Occupational Regulation and its Impact*. London: UKCES.

Fuller, A. and L. Unwin. 2006. 'Expansive and Restrictive Learning Environments', in Evans, K., Hodkinson, P., Rainbird, H. and Unwin, L. (eds) *Improving Workplace Learning, London*: Routledge.

Fuller, A. and L. Unwin (eds.). 2012. *Contemporary Apprenticeship: International Perspectives on an Evolving Model of Learning*. London: Routledge.

Green, F and Y. Zhu. 2010. 'Over-qualification, Job Dissatisfaction, and Increasing Dispersion in the Returns to Graduate Education.' *Oxford Economic Papers*, 62: 740-763.

Guest, D., J. Michie, M. Sheehan and N. Conway. 2003. ‘A UK Study of the Relationship between Human Resource Management and Corporate Performance’. *British Journal of Industrial Relations*, 41: 291–314.

Holmes, C. and Mayhew, K. 2012. *The Changing Shape of the UK Jobs Market and its Implications for the Bottom Half of Earners*, London: Resolution Foundation.

House of Commons. 2009. *Putting Science and Engineering at the Heart of Government Policy*. London: House of Commons

House of Commons Library. 2011. ‘Apprenticeships Policy.’ Standard Note SN/EP 3-052. Updated 04 November 2011. London: House of Commons.

Kleiner, M. 2006. *Licensing Occupations*. Kalamazoo: Upjohn Institute.

Kleiner, M. 2013. *Stages of Occupational Regulation*. Kalamazoo: Upjohn Institute.

Lewis, P.A. 2012a. *Flying High: A Study of Technician Skills and Training in the UK Aerospace Industry.* London: The Gatsby Charitable Foundation.

Lewis, P. 2012b. *Space for Technicians? An Analysis of Technician Duties, Skills, and Training in the UK Space Industry*. London: The Gatsby Charitable Foundation.

Lewis, P.A. 2013. *Technician Roles, Skills and Training in the UK Chemical Industry: An Analysis.* London: The Gatsby Charitable Foundation.

Lewis, P. and H. Gospel. 2011. *Technicians under the Microscope: A Study of the Skills and Training of University Laboratory and Engineering Workshop Technicians*. London: The Gatsby Charitable Foundation.

Lloyd, C. 2005. ‘Training Standards as a Policy Option: The Regulation of the Fitness Industry’, *Industrial Relations Journal*, 36: 367-386.

Loveridge, R., B. Roberts and J. Gennard 1972. *Reluctant Militants: A Study of Industrial Technicians*. London: Heinemann.

Marsden, D. 1986. *The End of Economic Man? Custom and Competition in Labour Markets*. Brighton: Wheatsheaf Books Limited.

Marsden, D. and P. Ryan. 1990. ‘Institutional Aspects of Youth Employment and Training Policy in Britain.’ *British Journal of Industrial Relations*, 28: 351-69.

Marsden, D. and P. Ryan. 1991. ‘Initial Training, Labour Market Structure and Public Policy: Intermediate Skills in British and German Industry.’ In P. Ryan (ed.), *International Comparisons of Vocational Education and Training for Intermediate Skills*. London: The Falmer Press.

McGovern, P. 1998. *Human Resource Management, Technical Workers, and the Multinational Corporation*. London: Routledge.

Meiksins, P and C. Smith. 1996. *Engineering Labour: Technical Workers in Comparative Perspective*. London: Verso.

Richard, D. 2012. *The Richard Review of Apprenticeships*. London: Department of Business, Innovation and Skills.

Ryan, P. 1995. ‘Adult Learning and Work: Finance, Incentives and Certification.’ In D. Hirsch and D. Wagner (eds.), *What Makes Workers Learn: The Role of Incentives in Adult Education and Training*. Creskill, NJ.: Hampton Press.

Ryan P. 2000. ‘The Attributes and Institutional Requirements of Apprenticeship: Evidence from Smaller EU Countries.’ *International Journal of Training and Development*, 4: 42-65.

Ryan, P., P.A. Lewis and H. Gospel. 2006. ‘Educational and Contractual Attributes of the Apprenticeship Programmes of Large British Employers.’ *Journal of Vocational Education and Training*, 58: 359-83.

Ryan, P., P.A. Lewis and H. Gospel. 2007. ‘Large Employers and Apprenticeship Training in the UK.’ *British Journal of Industrial Relations*, 45: 127-53.

Sandford Smith, D., P. Lewis and H. Gospel. 2011. ‘Technician Registration.’ In *Technical Education for the 21st Century*. London: Gatsby Foundation

Shapin, S. 1989. ‘The Invisible Technician.’ *American Scientist*, 77: 554-63.

Spilsbury, M. and R. Garrett. 2011. ‘The Future Demand for Technicians and Underlying STEM Skills.’ London: The Gatsby Charitable Foundation.

Stevens, M. 1994. ‘A Theoretical Model of On-the-job Training with Imperfect Competition’. *Oxford Economic Papers*, 46: 537–562.

Steedman H. 2012. *Overview of Apprenticeship Systems and Issues*. Geneva: International Labour Organisation.

Tamkin, P., L. Miller and J. Williams. 2013. *Understanding Occupational Regulation*. London: UKCES.

Technician Council. 2011. ‘The Technician Council’. London: The Technician Council.

UKCES. 2014. *Growth Through People: Evidence and Analysis*. Wath-upon-Dearne: UKCES.

Wolf, A. 2009. *An Adult Approach to Further Education*. London: The Institute of Economic Affairs.

Wolter, S.C. and P. Ryan. 2010. ‘Apprenticeship.’ In R. Hanushek, S. Machin and L. Wössmann (eds.), *Handbook of the Economics of Education*, Volume 3. Amsterdam: Elsevier Elsevier.